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GLASS COLOR STANDARDS FOR EXTRACTED HONEY*

By B. A. Brice, A. Turner, Jr.,† and J. W. White, Jr. (Eastern Regional Research Laboratory,‡ Philadelphia 18, Pa.)

The colors of commercial extracted honeys, in thicknesses of about 30 mm, range continuously from a pale yellow through amber to deep red or even black, depending on floral source and composition. In general, the lighter colors are associated with delicate flavors and the darker colors with strong flavors and less attractive appearance. It is natural, then, that color has been for many years a factor in the grading and marketing of honey. In 1925 the Department of Agriculture established grade standards for extracted honey and adopted the Pfund Color Grader for classification of its color (1, 2). The color classes were designated Water White, Extra White, White, Extra Light Amber, Light Amber, Amber, and Dark. The boundaries or cut-off points between these classes were defined in terms of selected scale readings (3) on the Pfund instrument, corresponding to settings of an amber glass wedge that furnishes a one-dimensional scale of chromaticity. Extracted honey may exhibit turbidity in varying degrees due primarily to colloidal matter and pollen, but this aspect of appearance is ignored in classification for color, which is done on the basis of chromaticity only.

In the Pfund Color Grader the sample of honey is placed in a wedge-shaped glass cell, which is mounted above the amber glass wedge and on the same movable metal frame. The gradients of the wedges are in opposite sense. Narrow vertical portions of the wedges are viewed, one above the other, through rectangular apertures (5.5×16 mm, with an 8 mm dividing line). The usual illuminant is a 200 watt lamp, diffusor, and daylight filter. The wedges are moved simultaneously by rack and pinion until the nearest chromaticity match is obtained, and their position is read from a millimeter scale. If the average scale reading is 8 mm or less, the sample is classified Water White; if 16.5 mm or less but greater than 8, Extra White; if 34 mm or less but greater than 16.5, White; if 50 mm or less but greater than 34, Extra Light Amber; if 85 mm or less but greater than 50, Light Amber; if 114 mm or less but greater than 85, Amber; if greater than 114 mm, the sample is classified as Dark. A correction chart has usually been supplied with each instrument so that readings could be referred to those obtained on a standard instrument fitted with the primary standard wedge.[1]

* Presented in part before the Optical Society of America, Boston, Massachusetts, October 9–11, 1952; *J. Opt. Soc. Am.*, 42, 881 (1952) (Abstract).
Presented at the Seventieth Annual Meeting of the Association of Official Agricultural Chemists, Oct. 15–17, 1956, at Washington, D. C.
† Present address: Smith, Kline and French Laboratories, Philadelphia, Pa.
‡ A laboratory of the Eastern Utilization Research Branch, Agricultural Research Service, U. S. Department of Agriculture.

[1] Until recently, distribution and calibration of this instrument were handled by the Munsell Color Company, Baltimore, Md. This is now done by the manufacturer, Koehler Instrument Company, 168-56 Douglas Avenue, Jamaica, N. Y.

This instrument is simple to operate and a good chromaticity match can be quickly made for most samples; also, it furnishes a continuous one-dimensional scale of chromaticity that is useful to packers who wish to blend honey to a selected color. For purposes of official inspection of numerous samples, however, the Pfund Color Grader has not proved entirely satisfactory. Considerable time is required for repeatedly cleaning and drying the wedge cell. For many samples it is difficult to find a satisfactory chromaticity match, and in such cases the precision of wedge setting and agreement between observers is decreased. Finally, the primary standard wedge has not been characterized or described, and there is no clear assurance that it has been used in the same way throughout the years.[2]

The success of the Department's glass color standards for maple sirup (4, 5) suggested trial of the same type of glass standards and color comparator for extracted honey. Preliminary tests indicated that this project was feasible and would provide a more convenient method of classifying extracted honey for color. The problem was to duplicate in amber glass the colors of samples (in cells of 31.5 mm internal thickness) that had been prepared to give "standard" settings on a Pfund Color Grader. No changes in the color classes or spacings were contemplated, and there was no intention to prohibit the use of the Pfund Color Grader except for official classification. Preliminary glass color standards were made available in 1951 (6). These standards were replaced in 1953 with glasses conforming more accurately to the "cut-off" points of the primary standard wedge of the Pfund Color Grader. It is the purpose of this paper to report the details of this development and to present complete color specifications for the new glass standards.

MATERIALS AND METHODS

Honey.—Samples of extracted honey were warmed, clarified by filtration, and blended to give approximately standard wedge settings on a Pfund Color Grader.

Caramel Solutions.—Solutions were prepared individually by dissolving a commercial caramel concentrate[3] in warm glycerol (U.S.P.) with stirring until the final color, on cooling to room temperature, corresponded closely to "standard" readings on the Pfund Color Grader.

Containers.—A standard viewing thickness of 31.5 mm was adopted for color classification of extracted honey. Precision fused Pyrex glass cells of 10, 30, and 31.5 mm internal thickness were used for spectrophoto-

[2] Evidence was recently presented (see reference 5) that a considerable difference exists between the Pfund Color Grader scale as used in 1953 and in 1930. A survey of 27 Pfund Color Graders conducted by the present authors in 1952–53 revealed large discrepancies (± 7 to ± 10 mm) in "corrected" readings reported by various users for the same samples. The results strongly suggest that any instrument in use calibrated prior to April 1953 should be returned to the manufacturer for recalibration.

[3] "Burnt Sugar Caramel Liquid," obtained from S. Twitchell Company, Camden, N. J. Mention throughout this paper of commercial names or products does not imply recommendation or endorsement by the Department of Agriculture over other products of a similar nature not mentioned.

metric studies, and the 31.5 mm thickness was used for final color matching of solutions with glasses. For routine color classification square bottles of 31.5 mm internal thickness were adopted. This square bottle is the same container used for color classification of maple sirup (5), made by Hazel Atlas Glass Company under the designation No. 2653 French square tablet bottle, $1\frac{1}{2}$ inch square, 2 ounce capacity.

Pfund Color Grader.—The standard Pfund Color Grader No. 100 fitted with the primary standard wedge was used at the Munsell Color Company, Baltimore, Md. Pfund Color Grader No. 441, exhaustively calibrated by the authors directly against the standard equipment at Baltimore, was used at this laboratory.

Polarization Photometer.—Final color matching of standard solutions and glasses was done with a polarization photometer (7, pp. 157–159) equipped with a 6° circular field and with CIE Illuminant C, an incandescent lamp operated at a color temperature near 2854°K, plus Davis-Gibson filters (8).

Spectrophotometer.—Spectrophotometric nomenclature followed is that used in the sugar industry (9, 10) and differs only slightly from that recommended by the A.O.A.C. (11). Measurements of spectral transmittance were made on a General Electric recording spectrophotometer from 400 to 750 mμ and in some cases on a Beckman DU spectrophotometer from 380 to 400 mμ. Wavelength errors on the former instrument were judged not to exceed ± 0.5 mμ (at least from 440 to 700 mμ) by tests with a didymium filter (12) and with glass filters standardized for spectral transmittance by the National Bureau of Standards (13). In these tests and in measuring the transmittancy of solutions and transmittance of glasses for final colorimetric analysis, values were read from the instrument dial rather than from continuous recordings. Whenever a value was below about 0.11, a more accurate transmittancy or transmittance was calculated from a measurement on a thinner layer of solution or glass.

CIE Colorimetric Data.—Color specifications based on the 1931 CIE standard observer (7, 8) and Illuminant C for the final standard solutions and final glass color standards were calculated by using the weighted ordinate method of integration at 10 mμ intervals from 380 to 760 mμ. CIE data for a number of samples of extracted honey were evaluated less accurately from recorded transmittancy curves with the aid of a General Electric semi-automatic tristimulus integrator and the method of 30 selected ordinates.

CHARACTERIZATION OF HONEYS AND CARAMEL SOLUTIONS

The spectral characteristics of typical clarified extracted honeys and two caramel-glycerin solutions are shown in Fig. 1, plotted as absorbancy versus wavelength, both on logarithmic scales. The data were calculated to a sample thickness of 31.5 mm from transmittance measurements in thinner cells, with glycerin as a reference medium. The shapes of spectral curves plotted in this way depend only on the nature of the pigments or colorants present, and not on their concentration or on the thickness of the sample. A rough characterization of colorant identity, in the absence of appreciable turbidity, is provided by a ratio of absorbancies at two wavelengths. This was termed a "Q-ratio" by Peters and Phelps (14) when one of the wavelengths chosen was 560 mμ, and was used by them to

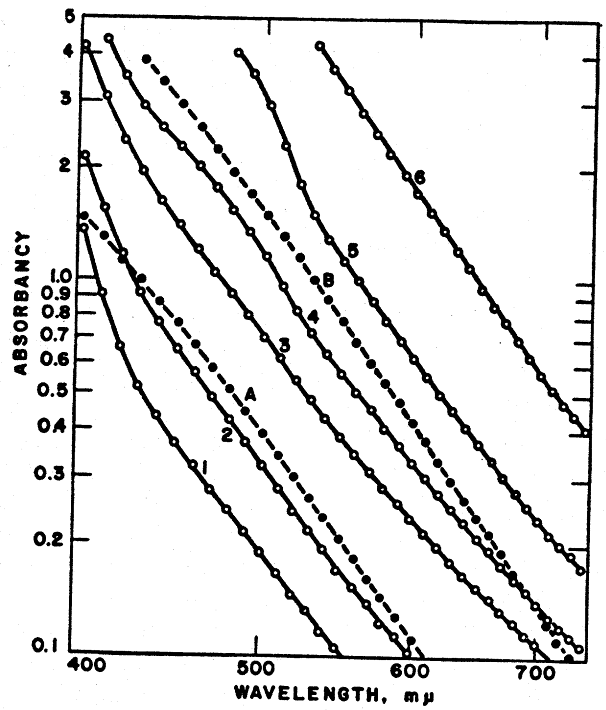

FIG. 1.—Spectral characteristics of typical clarified extracted honeys (curves 1–6) and caramel-glycerin solutions (curves A and B). Absorbancy and wavelength are both plotted on logarithmic scales. All data calculated to a thickness of 31.5 mm, with glycerin as a reference.

determine whether a given filtered sugar solution deviated from "normal" in spectral character. A more complete characterization studied by Liggett and Deitz (15) was the slope or "wavelength exponent" of the approximately linear curve relating logarithm of absorbancy and logarithm of wavelength. They showed that when these curves are accurately linear in the visible spectrum, they can be completely characterized by the wavelength exponent and the absorbancy index (attenuancy index if turbidity is present) at one wavelength, usually chosen as 560 mμ.

Data for absorbancy ratios (at wavelengths 500 and 560 mμ) and wavelength exponents for extracted honey, maple sirup (5), caramel-glycerin solutions (5), and limited data for filtered sugar solutions, are assembled in Table 1. These data and curves such as shown in Fig. 1 suggest that the principal colorants of honey, maple sirup, caramel solutions, and other sugar products are similar. Minor irregularities in the log A versus log λ curves (perhaps most pronounced in honey because of the possible presence of floral pigments), and variations in the data of Table 1, indicate minor variations in colorant composition in all these products. This variation is further shown by scattering of points in the CIE chromaticity diagram for honey and caramel solutions (Fig. 3), maple sirup (5), and sugar liquors (15, p. 266). The colors of none of these products are strictly one-dimensional with respect to chromaticity. A previous study of some of the spectral characteristics of honey was made by Phillips (16), but these data are of little practical use. A good discussion of the colorants in sugar products is given by Liggett and Deitz (15).

Caramel-glycerin solutions were used instead of honey in the standardization phases of the present investigation for the following reasons: They are shown by Fig. 1 and Table 1 to be good spectral matches for honey; they are free from variations in turbidity; and they are more easily adjusted to a desired color. Six standard caramel-glycerin solutions were prepared and carefully adjusted until average wedge settings for the final solutions on two Pfund Color Graders (including the primary standard) did not differ significantly from the nominal standard settings (3). The results are shown in Table 2. The average standard deviation from the mean of 10 settings (for one of the authors, B.A.B.) was ± 0.36 mm and was nearly constant over the entire range of wedge settings. For this observer, the means of two groups of 10 settings would have to differ by about 0.7 mm to be significantly different.

The six final solutions of Table 2 were assumed to typify the Department's color standards for extracted honey in respect to appearance, spectral character, and specified cut-off points on the Pfund Color Grader. These "standard" solutions were further characterized in a number of ways, as indicated in Table 3, for purposes of comparison with other color scales. The reference medium for the spectral and CIE data was clear colorless glass,[4] to compensate for reflection losses only and to permit characterization of the whole solution rather than the solute. The data include the basis for calculating cut-off points on three abridged or one-dimensional color scales used in the sugar industry. "Color Indexes" used for filtered sugar solutions are 1000 A_{420}/bc (17, 18) and 1000 A_{560}/bc (17) or simply A_{560}/bc (19, 20), where A is the absorbancy of the solution at the wavelength (mμ) indicated by the subscript, b is the thickness of solution and reference (usually water) in cm, and c is the concentration of sugar solids in g/ml. A widely used "Compensated Color Index" applica-

[4] Distilled water as a reference would give essentially the same results but would be less satisfactory at wavelengths greater than 700 mμ.

TABLE 1.—*Absorbancy ratio and wavelength exponent (slope of log A versus log λ curve) for various caramel-glycerin solutions, extracted honeys, and other sugar products*

PRODUCT	NO. OF SAMPLES	ABSORBANCY RATIO, A_{500}/A_{560}			WAVELENGTH EXPONENT,[e] n		
		AV.	STD. DEV.	RANGE	AV.	STD. DEV.	RANGE
Caramel-glycerin solutions[a]	5	2.12	±0.04	2.06–2.16	6.57	±0.20	6.37–6.82
Extracted honey[b]	10	2.22		2.00–2.48	7.03		6.14–8.22
Maple sirup, filtered[c]	29	2.15	0.25	1.78–2.72	6.75	1.01	5.10–8.86
Sugar liquors, filtered[d]	—	—	—	—	—	—	5.4– 8.5

[a] Brice and Turner, reference (5). Includes average value of preparations of Table 3.
[b] Six samples carefully clarified, four essentially free of turbidity.
[c] Brice and Turner, reference (5).
[d] Liggett and Deitz, reference (15).
[e] Calculated as $\Delta \log A/\Delta \log \lambda$ for wavelengths 500 and 560 mμ, except for samples 4 and 5 (Fig. 1) where an average slope was estimated.

Table 2.—*Wedge settings (mm) on the Pfund Honey Grader for caramel-glycerin solutions prepared to give "standard" settings; each entry is the average of 10 settings*

Date	Wedge	Water White	Extra White	White	Extra Light Amber	Light Amber	Amber
4–12	441[a]	8.6	16.9	34.5	50.1	84.4	113.5
4–15	Primary[b]	8.6	17.3	34.5	50.2	85.9	112.9
	Primary[b]	—	17.1	34.4	—	—	—
4–16	441	8.4	17.2	34.5	50.5	85.2	113.2
4–19	441	8.2[c]	—	33.7[c]	—	—	113.9[c]
		8.1[c]	—	33.9[c]	—	—	113.7[c]
Final solutions,							
Average setting		8.1[d]	17.1	33.8[d]	50.3	85.2	113.8[d]
Av. std. dev.[e]		±0.27	0.30	0.33	0.46	0.46	0.39
"Standard" setting[f]		8	16.5	34	50	85	114

[a] Readings by B.A.B. on Pfund Honey Grader No. 441 at Philadelphia, corrected (1953) by the equation W (corrected) $=0.992W$ (observed) $+1.1$.
[b] Readings by B.A.B. on standard Pfund Honey Grader fitted with primary wedge (certified by Mrs. Blanche R. Bellamy), at Munsell Color Company, Baltimore (1953).
[c] This solution was slightly readjusted in concentration on 4–19 to effect wedge settings closer to "standard" values.
[d] Does not include settings prior to final adjustment of concentration.
[e] Averaged for groups of 10 settings. Over-all average ±0.36 mm. (Observer, B.A.B.)
[f] Reference (3).

ble to filtered or unfiltered sugar solutions, proposed by Gillett (17, 18, 21) to compensate for normal turbidity, is $(1000/bc)(A_{420}^*-2A_{720}^*)$ where A^* is the attenuancy at the indicated wavelengths, in the nomenclature of Deitz (9) (attenuancy≡absorbancy in the absence of turbidity). Shown next in the table are the Q-ratios A_{500}/A_{560} and the wavelength exponents or slopes of the log A versus log λ curves (compare with Table 1). Since these values are not quite constant, the solutions differ slightly in spectral characteristics, probably because they were prepared individually instead of by simple dilution. Finally, complete CIE specifications are given in terms of the 1931 standard observer and Illuminant C. For purposes of color specification the CIE data furnish the only unambiguous characterization of these standard solutions.

GLASS COLOR STANDARDS

A number of commercial glasses were examined for suitability as color standards for extracted honey by comparison with standard caramel solutions (31.5 mm thick) similar to those of Table 3. Glasses manufactured by L. J. Houze Convex Glass Company, Point Marion, Pa., were found to be satisfactory. These glasses were available in the form of rolled sheets, only one side of which had to be ground and polished for adjustment to the desired color.

Final selection of melt and thickness of glass for each standard was

Table 3.—*Characterization of caramel-glycerin solutions prepared to give "standard" wedge settings on the Pfund Color Grader*

	Symbol	Water White	Extra White	White	Extra Light Amber	Light Amber	Amber	Average
Pfund Color Grader, mm	W[a]	8.1	17.1	33.8	50.3	85.2	113.8	
Absorbancy/cm	A_{420}/b[b]	0.237	0.378	0.692	1.11	(2.55)	(5.11)	
	A_{560}/b[c]	0.0434	0.0684	0.122	0.190	0.403	0.786	
	$(A_{420}-2A_{720})/b$[d]	0.207	0.338	0.632	1.03	(2.40)	(4.84)	
Absorbancy ratio	A_{500}/A_{560}[e]	1.99	2.00	2.03	2.06	2.13	2.16	2.06
Slope or wavelength exponent	n[f]	6.09	6.15	6.28	6.39	6.68	6.84	6.41
Chromaticity coordinates	x[g]	0.3829	0.4203	0.4814	0.5318	0.6111	0.6706	
	y	0.3957	0.4239	0.4480	0.4419	0.3865	0.3291	
Luminous transmittancy, %	T_c	70.3	58.1	39.5	25.3	7.80	1.56	
Dominant wavelength, mμ	Λ	576.4	577.9	581.3	585.5	596.9	611.6	
Excitation purity, %	P	40.9	58.5	81.3	93.2	99.5	100.0	

[a] From Table 2.

[b] At wavelength 420 mμ with clear glass as a "blank." This quantity, when multiplied by $1000/c$ has been used as a "Color Index" of filtered light-colored sugar solutions; see page 276 of reference (17); c is the concentration of sugar solids in g/ml (for honey $c = 1.15$); b is internal cell thickness in cm.

[c] At wavelength 560 mμ with clear glass as a blank. A_{560}/bc recommended by Zerban for filtered sugar solutions (19, 20).

[d] Used as "Compensated Color Index" of sugar solutions when multiplied by $1000/c$; Gillett, references (17, 18) and (21).

[e] "Q-Ratio," Peters and Phelps, references (14) and (15).

[f] Slope of log A vs. log λ curve (Fig. 1), calculated as $(1/0.049) \log (A_{500}/A_{560})$; see p. 260 of reference (15).

[g] CIE data based on 1931 standard observer and Illuminant C, for 3.15 cm thickness of solution with clear glass blank.

made visually with the Martens-type polarization photometer (7, p. 157–159) and CIE Illuminant C. This instrument was ideal for the purpose. The procedure was to prepare several thicknesses from the melts which showed promise as a color match; select a sample that was a little "darker" than the standard solution; grind the sample on a plate with No. 320 carborundum; place the ground sample at one aperture of the photometer and the standard solution in a precision 31.5 mm cell at the other aperture; adjust the photometer to give equal luminance in the two halves of the 6° field; and examine the chromaticity difference between glass and solution. The grinding was continued until a close chromaticity match was obtained. The thickness of the glass was measured, and several samples from the same melt were ground and polished to this thickness, then re-examined in the photometer. For this examination the glass was backed with a glass cell filled with distilled water 31.5 mm thick, since water was to be used as a blank in color classification with the glass standards. A polished glass showing a close chromaticity match with the solution was selected as a master standard. No difficulties were encountered except with the standard for White. With the glass available a close simultaneous match for hue and saturation could not be effected. In this case the thickness of glass was adjusted for the best chromaticity match with the solution, a compromise between a match for hue and a match for saturation. For all the standards it was noted that the chromaticity matches between the glasses and solutions were not as good for Illuminant A as for Illuminant C.

The glass standard for Water White was made up of two thicknesses of the same type of glass in contact (not cemented), since the stock glass used was not thick enough. The standard for Amber was made up of two components, a bright red and a "neutral" glass, with the thickness of the latter adjusted to make the lightness of the combination about equal to that of the solution. All glasses were finished to approximately 37 mm square.

Spectral transmittance measurements were carefully made for the master glass color standards by the procedure previously indicated. The data are assembled in Table 4 and plotted in Fig. 2. Shown also in Fig. 2 are transmittancy curves for the standard caramel-glycerin solutions, with clear colorless glass as a reference. Specifications and complete colorimetric analysis for the master set of glass color standards are given in Table 5. Chromaticity differences between the standard caramel-glycerin solutions and the master glass standards are shown in terms of MacAdam units (22) calculated from the x and y chromaticity coordinates of Tables 3 and 5. The differences shown, averaging 2.3 units, were considered acceptable for this work.

Chromaticity coordinates are plotted in Fig. 3 for the glass standards, and for the standard solutions and typical honey samples in 31.5 mm

TABLE 4.—*Spectral transmittance of master set of glass color standards for extracted honey (25–28°); values in parentheses calculated from measurements on thinner glasses*

WAVELENGTH, $m\mu$	WATER WHITE	EXTRA WHITE	WHITE	EXTRA LIGHT AMBER	LIGHT AMBER	AMBER
380	0.246	0.135	(0.0176)	(0.0031)	—	—
390	.228	.121	(.0160)	(.0024)	—	—
400	.218	.110	(.0152)	(.0018)	—	—
410	.213	.108	(.0155)	(.0016)	—	—
420	.219	.112	(.0174)	(.0017)	—	—
430	.233	.123	(.0212)	(.0022)	—	—
440	.256	.142	(.0284)	(.0033)	—	—
450	.287	.171	(.0401)	(.0055)	—	—
460	.323	.206	(.0570)	(.0095)	(.00001)	(.00001)
470	.365	.246	(.0792)	(.0157)	(.00002)	(.00002)
480	.411	.294	.108	(.0259)	(.00008)	(.00004)
490	.457	.344	.144	(.0408)	(.0003)	(.00007)
500	.504	.397	.189	(.0618)	(.0008)	(.00014)
510	.548	.451	.239	(.0896)	(.0021)	(.00025)
520	.590	.505	.295	.124	(.0049)	(.00046)
530	.628	.555	.354	.166	(.0108)	(.00093)
540	.661	.605	.415	.218	(.0219)	(.0020)
550	.690	.647	.473	.273	(.0393)	(.0032)
560	.715	.688	.528	.331	(.0647)	(.0045)
570	.736	.720	.579	.388	(.0980)	(.0062)
580	.752	.749	.624	.443	.137	(.0085)
590	.765	.773	.661	.493	.182	(.0118)
600	.775	.790	.691	.534	.225	(.0221)
610	.782	.806	.715	.570	.265	(.0474)
620	.786	.815	.733	.599	.302	(.0768)
630	.789	.823	.747	.623	.333	(.0920)
640	.790	.830	.759	.643	.361	.104
650	.791	.835	.768	.661	.387	.122
660	.790	.839	.776	.677	.412	.154
670	.789	.842	.782	.692	.435	.210
680	.787	.844	.786	.705	.458	.286
690	.785	.845	.790	.717	.478	.359
700	.782	.846	.791	.728	.497	.417
710	.778	.846	.792	.737	.514	.462
720	.774	.845	.792	.745	.529	.498
730	.770	.844	.791	.752	.541	.527
740	.766	.842	.789	.757	.550	.555
750	.762	.840	.786	.761	.556	.572

thickness. The average locus of chromaticities and scattering of points for the liquids is similar to that found for maple sirup (5) and other sugar products (15).

DUPLICATE STANDARDS AND COLOR TOLERANCES

Sufficient glass was purchased by the Department of Agriculture to assure a supply which would meet the estimated future requirements of

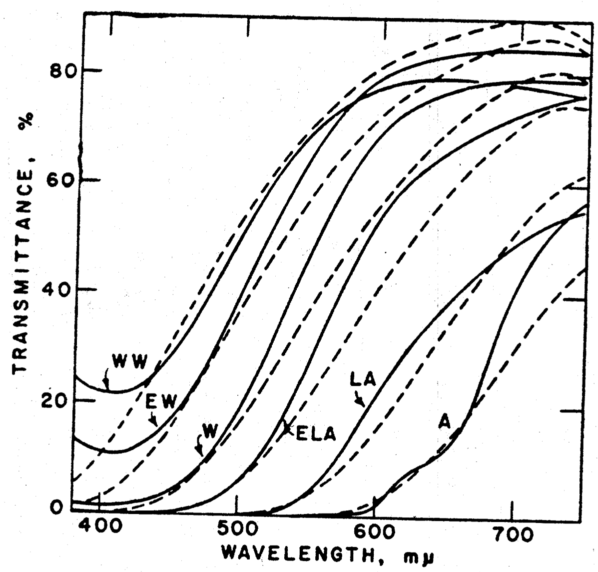

FIG. 2.—Spectral transmittance of "standard" caramel-glycerin solutions (dotted curves) in cells of 31.5 mm internal thickness, relative to that of clear glass; and spectral transmittance of glass color standards (solid curves) matching the colors of the respective solutions.

government inspection agencies and the industry for duplicate sets of standards. Because of small variations of color ordinarily present within a given melt of glass, and because of unavoidable deviations from thickness specifications in grinding and polishing operations, it was necessary to establish color tolerances and a simple procedure for testing duplicate standards.

Six series of glasses were selected, one series for each of the color standards, in which the individual pieces differed significantly in transmittance relative to that of the master standard at a selected wavelength. For convenience, the wavelength selected (except for the Amber standard) was that showing a transmittance of 30.0 per cent for the master standard. In general the transmittances of the glasses in a series ranged from about 28 per cent to 32 per cent, the extremes including glasses considered not acceptable as color matches for the master standards. From each series, glasses representing acceptable "light" and "dark" limits were selected by visual comparison of each glass with a master standard. The glasses (37 mm square) were held in close juxtaposition 12 to 18 inches from the eye, or were held as filters close to the eye in quick succession; overcast sky was used as a source. These conditions are comparable with those preferred for color classification of extracted honey.

Spectral transmittances of all glasses in the series were measured, and tristimulus values and chromaticity coordinates were calculated for Illuminant C. The chromaticity difference between each glass and the

TABLE 5.—*Specifications and colorimetric analysis for master set of glass color standards for extracted honey; CIE data are based on 1931 standard observer and Illuminant C*

		WATER WHITE	EXTRA WHITE	WHITE	EXTRA LIGHT AMBER	LIGHT AMBER	AMBER
Glass designation[a]		Amber 253LT	Amber 253NS	Amber 253MM	Amber 66DK-M1	Amber 66DK-M1	Cherry ALH-4 +Med. Smoke MM
Thickness, mm, b		2.90[b]	1.23	2.19	1.87	4.87	1.15+1.56
Tristimulus values $\times 10^{-2}$:	X	64.854	62.974	51.411	38.120	15.700	3.161
	Y	67.656	64.111	48.662	31.905	9.830	1.545
	Z	37.372	23.951	7.337	1.674	0.035	0.005
Chromaticity coordinates:	x	0.3818	0.4169	0.4786	0.5317	0.6141	0.6711
	y	0.3982	0.4245	0.4531	0.4450	0.3845	0.3279
Luminous transmittance, %, T_c		67.7	64.1	48.7	31.9	9.83	1.54
Dominant wavelength, mμ, λ		575.8	577.8	580.5	585.2	597.4	612.0
Excitation purity, %, P		41.2	57.0	81.9	93.9	99.7	99.8
Color diff., solution-glass,[c] ΔS		1.7	2.5	4.0	1.7	2.6	1.1

[a] L. J. Houze Convex Glass Co. designation.
[b] Comprises two separate components of Amber 253LT each 1.45 mm thick (not cemented).
[c] MacAdam units of chromaticity difference, calculated from x and y values of Tables 3 and 5.

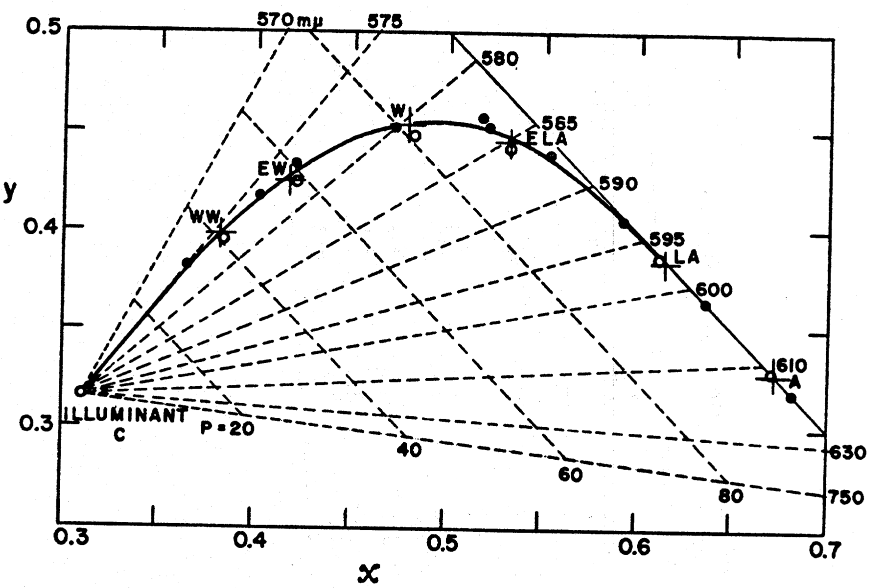

FIG. 3.—CIE chromaticity diagram, showing coordinates for the six glass color standards (+); for "standard" caramel-glycerin solutions in 31.5 mm thickness (○); and for typical samples of extracted honey (●).

corresponding master standard was calculated in terms of MacAdam (22) units (ΔS) and in terms of the distance between points on the x, y chromaticity diagram (ΔC). Color differences in NBS units (ΔE) were calculated from the tristimulus data by the Adams-Nickerson formula with $f=50$ (7, pp. 265–267, 352–357). The glasses selected to represent approximate acceptable limits showed roughly constant differences from the master standards on all three of these scales. Agreement was best when compared with ΔE values, which ranged from 1.2 to 1.9 units and averaged 1.6 units. A color tolerance of ± 1.6 NBS unit, which corresponds approximately to a just-noticeable difference, was adopted for the preparation of duplicate standards. This tolerance was converted to acceptable transmittance units at wavelength λ by plotting ΔE versus T_λ from 28 to 32 per cent for all six series of glasses discussed above. The data are shown in Table 6. Tolerances in terms of other units were obtained from plots of ΔS and ΔC versus T_λ after the limits for transmittance had been adjusted to correspond to ± 1.6 NBS units. All plots were linear. Corresponding tolerances for thickness of glass were calculated from the transmittance limits (Table 6) and the actual thickness of the master standards (Table 5). For the maple sirup color standards (5), a chromaticity tolerance of ± 2.5 MacAdam units was adopted. Since these color standards are in the color range of White to Light Amber on the honey scale, it is apparent

TABLE 6.—*Color tolerances adopted for testing and producing duplicate glass color standards, based on $\Delta E = \pm 1.6$ NBS unit of color difference*

	WATER WHITE	EXTRA WHITE	WHITE	EXTRA LIGHT AMBER	LIGHT AMBER	AMBER
Test wavelength (approx.), $m\mu$, λ	454	481	521	554	619	578[b]
Transmittance, master standard, near λ, %, T_s	30.0[a]	30.0	30.0	30.0	30.0	1.00[b,c]
Tolerances for duplicate standards:						
Units of % transmittance near λ, ΔT	±1.3	1.2	1.1	1.2	0.9	0.15[b,d]
NBS units (Adams-Nickerson formula),[e] ΔE	±1.6	1.6	1.6	1.6	1.6	1.6
MacAdam units, chromaticity diff.,[f] ΔS	±1.4	1.8	2.4	2.8	2.2	4.9
CIE chromaticity difference,[g] ΔC	±4.0	4.1	3.4	3.6	2.9	6.2
Units of glass thickness, mm: Δb	±0.12	0.04	0.07	0.07	0.13	0.06[b]
$100\ \Delta b/b$	4.1	3.3	3.2	3.7	3.7	5.2[b]

[a] The two components tested together (not cemented).
[b] Applies to test of cherry component only (Table 5).
[c] Transmittance relative to cherry component of master standard T/T_s.
[d] Units of relative transmittance.
[e] $\Delta E = 50\{(0.23\Delta V_Y)^2 + [\Delta(V_X - V_Y)]^2 + [0.4\Delta(V_Z - V_Y)]^2\}^{1/2}$.
[f] $\Delta S = [g_{11}(\Delta x)^2 + 2g_{12}\Delta x\Delta y + g_{22}(\Delta y)^2]^{1/2}$.
[g] $\Delta E = 1000[(\Delta x)^2 + (\Delta y)^2]^{1/2}$.

from Table 6 that the tolerances adopted for the maple and honey color standards are essentially equal.

The measurement of transmittance of finished glasses at one wavelength, with established tolerances in these units (Table 6), furnishes a rapid method of testing duplicate standards for acceptability, and can be done by technicians inexperienced in color matching. The method is differential and hence essentially free from errors of wavelength and photometric scale. For the White color standard, for example, the spectrophotometer is set at a wavelength to indicate a transmittance of 30.0 per cent with the master standard as a sample. The transmittances of a series of duplicate standards are then measured in rapid succession and those having transmittances higher than 31.1 per cent or lower than 28.9 per cent are rejected. (For some types of spectrophotometers the measurements and data would be more conveniently expressed in terms of transmittance relative to that of the master standard.)

The technique was extended also to the testing of stock glasses prior to grinding and polishing in order to reduce the number of rejections. Stock glasses were cut into 37 mm squares and placed in the spectrophotometer at the wavelength required to show 30.0 per cent transmittance for the master standard. The thickness and transmittance of each piece was recorded. The thickness required to give a transmittance of 30.0 per cent, and hence standard color, was then quickly determined by reference to a calculated curve relating transmittance (10 to 32 per cent) to relative thickness (absorbancy ratio). This curve was nearly linear and could be used for all the standards of Table 6 (except Amber) and for the maple standards (5). For example, a stock glass with a transmittance of 11.0 per cent would require that its measured thickness be reduced by a factor 0.526 (i.e., absorbancy ratio, corrected for surface reflection losses) in order to have a standard transmittance of 30.0 per cent. Because of small color variations within some of the melts, the calculated thickness would not necessarily be the same as the thicknesses of the master standards (Table 5). Stock glasses tested in this way were placed in groups having nearly the same predicted thickness. Grinding and polishing were then performed batch-wise on these groups, and very few rejections resulted unless thickness tolerances (Table 6) were exceeded.

A special procedure was required for handling the red component of the standard for Amber. This glass had a steep transmittance curve from 590–640 mμ with a very high temperature coefficient of transmittance in this range; as a result, the 30 per cent transmittance method was unreliable. It was found, however, that low transmittances on the broad toe of the curve (530–580 mμ) were less sensitive to temperature; also, by means of the polarization photometer, it was found that chromaticity matches were not noticeably changed by relatively large temperature changes. A successful procedure for testing these components was to measure transmittance of a specimen relative to that of the master standard (T/T_s) at the mercury wavelength 578 mμ in a spectrophotometer or filter photometer (23) capable of measuring relative transmittances precisely at greatly reduced levels of illumination (the transmittance of the standard component at this wavelength was approximately 4 per cent). As shown in Table 6, glasses were rejected if T/T_s was outside the limits 1.00 ± 0.15. The technique was also applied to the examination of stock glasses. The thickness required to give standard color was readily determined by measuring T/T_s and referring to a calculated curve relating T/T_s to relative thickness (absorbancy ratio). The neutral component of the standard for Amber (Table 6) required no testing, since small variations in thickness did not noticeably affect the color of a combination.

COLOR COMPARATORS

The color comparators adopted for use with the glass standards in classifying extracted honey for color were identical with those devised for maple sirup (5) and are illustrated in Fig. 4. The three lighter glass standards are mounted behind alternate apertures 30 mm square in one comparator, and the three darker standards are mounted in a second comparator. Square bottles of 31.5 mm internal thickness, filled with distilled water, are placed in the compartments behind the glass standards to serve as blanks and to duplicate the appearance of filled bottles of extracted honey when the observer looks through the standard apertures. A square bottle filled with extracted honey to be classified is placed in one of the compartments between adjacent standards. The comparator is held 12 to 18 inches from the eye and a color comparison is made with natural or artificial daylight used as a source.

Three turbid suspensions designated Cloudy 1, Cloudy 2, and Cloudy 3 are provided in square bottles as accessories to aid in classifying extracted honey having noticeable turbidity. These are suspensions of diatomaceous earth (Johns-Manville Hyflo Super-Cel) in concentrations of 100, 200,

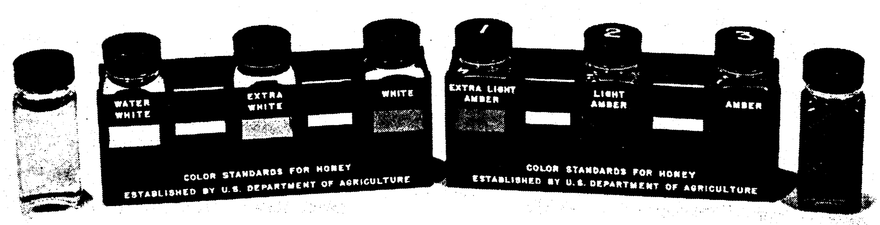

FIG. 4.—Color comparators for extracted honey, showing the six glass color standards mounted as windows, backed by three clear blanks and by the three cloudy suspensions 1, 2, and 3 in square bottles; and two samples of honey to be classified.

and 400 mg/l in distilled water. When a turbid honey is to be classified, the clear blanks are replaced by the cloudy suspensions, which may be switched from compartment to compartment until a final comparison is made between the sample and a glass standard (backed by a cloudy suspension) at about the same level of luminance. Tests with the polarization photometer indicated that superposing a cloudy suspension on a glass standard does not perceptibly disturb a chromaticity match, although the suspensions are slightly selective in spectral transmittance.

The average internal thickness of the square bottles is 31.5 mm with a standard deviation of about ± 0.4 mm. They are not of good optical quality, but are convenient, inexpensive, and adequate for routine color classification. Errors can occur only when the chromaticity of the honey is near that of a standard. More precise classification, or refereeing a disputed color grade, can be done in the laboratory by using optical cells of 31.5 mm internal thickness, the master glass color standards, and a polarization photometer with CIE Illuminant C.

Features of the new color comparators contributing to more precise color classification of extract honey are: The relatively greater thickness of sample viewed, resulting in a much wider spacing of standards on a chromaticity scale; large square viewing apertures (30×30 mm) with a relatively narrow dividing line (9 mm) between standard and sample apertures; and finally, use of color standards that are completely described in the CIE coordinate system, with established color tolerances for duplicate standards.

As stated earlier in the paper, color classification of extracted honey is done on the basis of chromaticity only; the glass color standards furnish boundary points for the color classes on a one-dimensional chromaticity scale.

The glass standards became the official United States Department of Agriculture color standards for extracted honey in 1951 and were adjusted to their present form in 1953. Complete grading sets are available commercially from the Phoenix Precision Instrument Company, Philadelphia, Pa. About 200 sets are now in use by the industry and by government inspection agencies.

SUMMARY

Previous official color standards for extracted honey were defined in the Department's grade standards in terms of six scale readings on the Pfund Color Grader. In order to provide a more convenient and economical method of official classification for color on the basis of the U.S. standards for grades of extracted honey, six glass standards and simple color comparators were developed. The glasses were close chromaticity matches for caramel-glycerin solutions in 31.5 mm thickness, and were prepared to give the required scale readings in terms of the primary standard wedge

of the Pfund Color Grader. The "standard" caramel-glycerin solutions were shown to be spectrophotometrically similar to samples of clarified extracted honey, and were characterized in terms of several one-dimensional color scales in use in the sugar industry. Complete specifications for the glass color standards and the caramel-glycerin solutions were presented in the CIE coordinate system.

Color tolerances were established in NBS units of color difference, and a simple one-wavelength method of testing glasses was developed for the production of duplicate glasses.

ACKNOWLEDGMENTS

The project was carried out in cooperation with the Processed Products Standardization and Inspection Branch of the Agricultural Marketing Service. The suggestions and continued interest of F. L. Southerland and his staff are gratefully acknowledged. The authors are indebted to Henry J. Scherr for grinding and polishing glasses.

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